The US Army burn center: Professional service during 10 years of war

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Since 1952, the US Army Institute of Surgical Research (USAISR) Burn Center has provided comprehensive care for patients who have sustained severe thermal trauma, inhalation injury, and other diseases related to burn trauma. The Army Burn Center serves the entire population encompassed by the military health care system as well as veterans and civilian emergency patients requiring burn center care within the 26,000-sq mi trauma service area surrounding San Antonio, Texas. US military engagement following the events of 9/11 markedly changed the number and type of patients with burn injury treated at our center and the system used to care for them. We report our experience and summarize the most noteworthy changes in practice implemented during these 10 years of war.

As the number of patients admitted to our center rose during the decade of combat operations, the mix of military versus civilian patients varied considerably (Fig. 1). The first military casualty from overseas contingency operations, initially referred to as the Global War on Terrorism, arrived at our burn center in March 2003; between the start of Operation Enduring Freedom in October 2001 and March 2003, there were no combat-related injuries warranting burn center care[1] (Table 1). The mechanism of thermal injury among those evacuated from Iraq and Afghanistan was predominantly from fire and flame injury related to effects of explosives; however, other noncombat-related injuries predominated during the early part of the engagement.[2] Explosions represent the single largest mechanism of injury for combat-related burn casualties[3] (Fig. 2).

THE BURN CARE TEAM

Verified jointly by the American Burn Association and the American College of Surgeons' Committee on Trauma, the USAISR Burn Center relies on the concerted efforts of a multidisciplinary team of professionals to accomplish its mission. The interdisciplinary team is composed of 20 different occupational specialties, either assigned as military personnel or used as federal civilians or contract personnel (Table 2). Continuous collaboration and communication among a multidisciplinary staff are crucial for success and typify leading burn centers. The cornerstone of communication is daily multidisciplinary rounds, which include bedside presentation of all patients. The team is able to simultaneously correlate physical and laboratory data, radiographic assessment, and consultant recommendations to solidify the care plan approved by the attending physician relatively early in the day. This patient-centered process improves communication, increases both efficiency and productivity, and has repeatedly been highlighted as a best practice within the facility.

Nursing Staff

At the very core of the Burn Center reside nursing professionals representing a wide range of expertise and training. Among the approximately 100 registered nurses (RNs), both military and civilian, working at the Burn Center, 12 serve as critical care registered nurses and 5 as advanced practice nurses with critical care nurse specialist certification. The nursing staff also includes 70 licensed vocational nurses and 6 certified nursing assistants.

Burn care, like other specialty care, requires unique skills and knowledge not rapidly acquired or produced. Burn nursing includes intricate wound care, management of highly complex patients, and the requirement to maintain proficiency in multiple advanced technologies. The ability to provide burn care to large numbers of casualties, either locally or as a forward-deployed augmentation package, demands a highly experienced core staff that can be supplemented as necessary to respond to rapid influx of patients. A dramatic increase in staffing occurred during the first year of combat operations in Iraq and required an enormous commitment from staff at all levels to orient and train personnel previously unfamiliar with burn care.

Medical Staff

Physicians working at the military's burn center are predominantly general surgeons board certified in surgery with additional training in plastic surgery, trauma, and/or surgical critical care. Physicians specialized in anesthesiology, medical intensive care, physical medicine and rehabilitation, and

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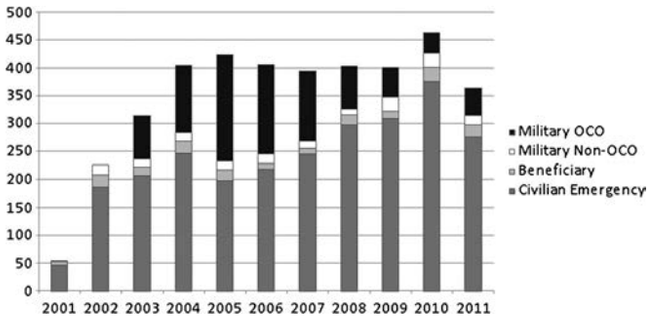

Figure 1. Burn Center admissions October 2001 through October 2011.

pathology comprise the remainder of the medical staff; all physicians, regardless of specialty, are actively engaged in collaborative clinical research. The incorporation of a medical intensivist and physiatrist in 2005 greatly expanded our ability to provide comprehensive care on multiple levels.

Coinciding closely with the expanded workload that followed 9/11, certified physician assistants (PAs) proved themselves to be an indispensable part of clinical operations. Serving as midlevel providers, the group grew from just one PA in 2001 to six full-time PAs by 2011. Their role includes almost every aspect of the surgical care at the burn center, including on-call coverage in the burn intensive care unit (BICU), first-assistant roles in the operating room (OR), and management of patients in the ward and in the outpatient clinic.

ACUTE CARE

Civilian emergency patients are admitted to the burn center for acute care via three routes: through the emergency department of our Level 1 trauma center, through the burn clinic, or in transfer from an outside facility. Patients who arrive after receiving their initial care at an outside hospital are accepted in transfer using a regional referral system, which encompasses 53 hospitals from 22 counties surrounding San Antonio. A centralized coordination center connects the referring physician with the burn surgery attending physician on call to facilitate rapid acceptance and transfer of patients meeting transfer criteria as outlined by the South Texas Regional Advisory Council for trauma care.

Military casualties with burns and other soft tissue trauma or illness are accepted using a system that spans the globe. The Global Patient Movement Regulating Center coordinates worldwide evacuation of military casualties. Military health care providers worldwide may contact the burn center via telephone or e-mail to receive consultation from Burn Center surgeons and acceptance of referrals for transfer. Between January 2005 and October 2011, this worldwide

TABLE 1. Patient Demographics

Patients	n	Mean Age, y	Mean Percent TBS	Mean ISS
Military (OCO)	895	25.4 (18 52)	15.2 (0 95)	12.3 (0 75)
Military (non-OCO)	168	26.9 (18 50)	11.0 (0 84)	7.3 (0 51)
Beneficiaries	181	48.7 (1 81)	7.8 (0 69)	4.8 (0 41)
Civilian emergency	2,599	41.9 (1 94)	12.2 (0 100)	7.5 (0 75)
Total	3,843	37.7 (1 94)	12.6 (0 100)	9.0 (0 75)

OCO, overseas contingency operation.

Figure 2. Burn amputee.

TABLE 2. Clinical Staff by Specialty Certification

Nursing
RN*
Licensed vocational nurse
Certified nursing assistant
OR
Anesthesiologist
Anesthesia technician
OR Technician
Rehabilitation
Physical medicine and rehabilitation
Physical therapist and assistant
Occupational therapy and assistant
RT
Certified respiratory therapist
Registered respiratory therapist
Clinical nutrition
Registered dietician
Dietary technician
Social work and case management
Licensed clinical social worker
Intensive care
Medical intensivist (medical critical care)
Surgical intensivist (surgical critical care)
Surgery
General surgeon
Plastic and reconstructive surgeon
Physician assistant

*RN subspecialization at our center includes critical care registered nurse, psychiatric clinical nurse specialist, OR nurse, infection control, and case management.

electronic consultation service was used 159 times, with an average reply time of less than 4 hours.

Patients with burns requiring formal resuscitation are generally admitted to our BICU. Other patients routinely admitted to the BICU include those with inhalation injury, chemical injury, extensive soft tissue diseases requiring resuscitation, and those with coincident soft tissue trauma requiring immediate surgical treatment. BICU care during the initial 24 hours after burn remains extremely challenging because resuscitation must balance the need to perfuse end organs while not contributing to overresuscitation morbidity and/or mortality such as extremity or abdominal compartment syndromes.[4–6] During the past 10 years of conflict in both the Iraqi and Afghan theaters, it has become clear that fluid resuscitation should be carefully managed during global evacuation where multiple patient transfers between providers can disrupt the continuity of the initial resuscitation.[7–9]

The Modified Brooke formula (lactated Ringer's solution at 2 mL/kg/percent total burn surface area [TBS] divided over the first 24 hours] has been shown to reduce the amount of fluid given to the patient with burn injury when used as starting point for resuscitation compared with the Parkland formula (lactated Ringer's solution at 4 mL/kg/percent TBS divided over the first 24 hours) with adequate support of end-organ perfusion as measured by adequate urine output.[9–11] In a collective effort to standardize initial burn care provided in the combat zone and throughout the evacuation process, a theater clinical practice guideline (CPG) for burn resuscitation and accompanying burn resuscitation flow sheet (BRF) were developed in 2006. Refinement to this CPG has included development of a less difficult resuscitation fluid volume calculation termed the *Rule of Ten*.[12] Education regarding the intended use of the CPG and the BRF was provided through multiple predeployment courses. The CPG and the BRF facilitated theater-wide standardization of care for the burn casualty and resulted in improved outcomes for wounded warriors.[8,13]

Extending the CPG and the BRF, the USAISR developed Burn Resuscitation Decision Support (BRDSS) software, which automates calculations of adjustments to fluid resuscitation rate based on urine output. In calculating a proposed change, the BRDSS takes into account previous intravenous fluid resuscitation and urine output and limits adjustments to ±25% to avoid boluses of fluid, which promote edema formation and may lead to resuscitation morbidity. Our group demonstrated that use of BRDSS in the BICU can result in improved fluid management of severely burned patients as measured by reduced infusion volume, increased accuracy in urinary output targets, and reduced mortality compared with historical controls.[14,15] Use of computerized decision support systems is well incorporated into our daily practice; work is underway to obtain clearance from the US Food and Drug Administration to allow worldwide deployment of BRDSS software.

Routine use of minimally invasive hemodynamic monitoring was instituted at our center in 2005. Vigileo technology (Edwards Lifescience, CA) was adopted to provide cardiac function data to include cardiac output and vascular resistance. Vigileo also calculates the stroke volume variability, which can be trended to assist with estimation of volume responsiveness. The CRITICORE digital urimeter and thermometer (Bard Medical, Covington, GA) was incorporated into to our BICU practice in 2004 and became an integral component of our burn resuscitation practice.

Management of acute kidney injury (AKI) remains a challenge for the provider caring for patients with severe burns, with reported mortality for patients with burn injury exceeding 80%. We recently reported that the incidence of AKI in our burn population burn was as high as 33%.[16–19] Actions taken to address this problem included the selective use of continuous renal replacement therapy and fenoldopam. In November 2005, we implemented a continuous renal replacement therapy program organic to the BICU to support those with severe AKI. Before this time, the use of conventional intermittent hemodialysis was limited because of the hemodynamic challenges associated with the technique. Our group demonstrated that the application of continuous venovenous hemofiltration in adult patients with severe burns and AKI was associated with a 28-day decrease in hospital mortality when compared with historical controls, and clinical improvement was noted in patients with shock and acute lung injury and adult respiratory distress syndrome (ARDS).[16,17]

The apparent benefit of hemofiltration among burn casualties with AKI, specifically in those with concomitant septic shock, resulted in the American Burn Association's supporting a multicenter trial to evaluate continuous venovenous hemofiltration in patients with burns. Fenoldopam mesylate is a selective dopamine 1 receptor agonist found to be helpful in preserving renal function, which can decrease the need for renal replacement therapy and improve outcomes in critically ill patients.[20] Our experience with the off-label use of fenoldopam for AKI in patients with burn injury has been largely positive.[21]

RESPIRATORY THERAPY

An integrated respiratory therapy (RT) department composed of both certified respiratory therapists and registered respiratory therapists provides comprehensive pulmonary support for all patients admitted to the burn center.[22] All staff RTs maintain proficiency in the use of multiple modes of ventilator support, including airway pressure release ventilation, high-frequency percussive ventilation (HFPV), high-frequency oscillatory ventilation, as well as more traditional modes to support patients with inhalation injury and ARDS.[23,24]

The VDR-4 (Percussionaire, Sandpoint, ID), providing HFPV, remains a principal ventilator used within our burn center.[25] In those requiring mechanical ventilation, we demonstrated in a randomized control trial that HFPV resulted in outcomes no different from the widely adopted low-tidal volume strategy. Among patients with burn injury, especially those with smoke inhalation injury, HFPV may be preferred over a low-tidal volume strategy because most patients in the low-tidal volume arm did not tolerate this technique and required rescue ventilation.[26] For those patients who progress to ARDS, our center has increasingly used proning and/or inhaled nitric oxide as recently reported by Hale et al.[27] We currently implement inhaled nitric oxide therapy using the INOMAX device (Ikaria, Hampton, NJ) with both HFPV and traditional ventilatory support modes.

Frequent use of fiberoptic bronchoscopy, bronchoalveolar lavage, is readily supported by the burn center's RT department. Point-of-care arterial blood gas laboratory testing is immediately available in both the BICU and the OR; arterial blood gas testing was enhanced by the addition of lactate measurement.

BURN FLIGHT TEAM

One of the most unique and valued components of the USAISR Burn Center when compared with other centers is its integral flight team. The Army's burn flight team is a key and essential element within the very core of the burn center itself. Comprising military officers and noncommissioned officers assigned to the USAISR, the team consists of surgeons, critical care nurses at both the registered nurse and licensed vocational nurse level, and respiratory therapists. These individuals work daily in the BICU and are therefore continuously prepared to care for a critically injured burn casualty.

Since the 1950s, the burn flight team has provided worldwide transport of 365 patients with severe burn injuries and associated trauma.[28] Coupled with advanced medical equipment and long-range aircraft such as the US Air Force C17 Globemaster, the team provides the capability of a transportable BICU with global reach.[26,29] This system of selectively using specialized medical transport for the intercontinental evacuation of patients with severe burn injury has proven itself to be safe and effective.

Wound Care

Care of the unexcised burn and dressing of donor sites and fresh grafts remains a focus of wound care in any burn center. The use of topical antimicrobial creams such silver sulfadiazine (Silvadene, Flamazine) or mafenide acetate (Sulfamylon) remains widespread. The introduction of silver nylon dressings such as Silverlon and Silverseal provided new options for the provider caring for burn casualties at all echelons of care.[30] Similarly, negative-pressure wound treatment systems such as the Vacuum-Assisted Closure (V.A.C) system (KCI, San Antonio) have been adopted for use in the field of burn care as surgeons sought to prepare wound beds and secure fresh grafts to the excised wound bed.[31] Accurate documentation of the initial injury and progression of the wound healing process is facilitated by use of the USAISR's WoundFlow mapping software.

Infection Control

Prevention and treatment of infection related to survival of patients with burn injury demands constant and focused attention from a dedicated infection control nurse, working closely with infectious disease consultants.[32] Attention to hand washing practices, monitored and reported on an interval basis, is crucial. Equally important are measures designed to minimize central line–associated bloodstream infections, catheter-related urinary tract infections, and ventilator-associated pneumonia.

Perioperative Care

Three board-certified anesthesiologists, working full time at the USAISR, provide perioperative resuscitation and airway 33 Advances in airway management include the increased use of video laryngoscopy and numerous supraglottic airway devices to assist with oxygenation and ventilation in the burn OR along with a wide array of innovative management techniques. Intraoperative hemodynamic monitoring includes the use of transesophageal echocardiography and noninvasive continuous hemoglobin monitoring combined with minimally invasive cardiac output monitoring.

Advances in hemostatic resuscitation strategies and transfusion practices include the use of thromboelastography perioperatively combined with hemostatic transfusion practices learned during recent military support operations. Deliberate or permissive hypotension may be coupled with acute normovolemic hemodilution and thromboelastography-guided component-specific transfusion to facilitate our goal of hemostatic resuscitation. Expert anesthesia care ensures a smooth and pain-free wakeup, decreasing excessive movement, which may result in graft shear or loss and worsened surgical outcomes. Our armamentarium to optimize analgesia includes neuraxial approaches to perioperative analgesia, peripheral nerve blocks, immersive virtual reality, acupuncture, and the application of topical anesthetics.

In 2008, we identified a population of patients who became dependent on high doses of oral narcotics for daily pain management. A program to assist the patients in reducing their medication requirement was developed using ultra-rapid opioid detoxification under anesthesia as reported by our group in 2011.[34] Our experience with the ultra-rapid opioid detoxification under anesthesia process demonstrated successful realization of one of our goals for the opioid-dependent patients with burn injury—to simultaneously reclaim control of their lives and be relieved of severe pain.

Perioperative nurses and OR technicians assigned to the burn ORs are expert not only in all aspects of intraoperative care but also in the proper management of resources such as allograft and biosynthetic materials such as Integra. The importance of their role in the proper implementation of research protocols conducted in our OR cannot be overlooked.

Surgical Treatment

Surgical procedures are generally classified as acute wound care or reconstructive. Early excision and grafting has been shown to decrease the incidence of sepsis and invasive wound complications, although its effect on overall mortality has not yet been validated. It is now common practice to perform early and, when possible, complete excision within 3 days of admission on all patients admitted to our burn center. Military casualties evacuated from Iraq and Afghanistan generally undergo excision and grafting procedures shortly after their arrival at our facility.[35]

Wolf et al.[3] reported that despite longer time from injury to burn center arrival as well as higher Injury Severity Score (ISS) and higher incidence of inhalation injury, there was no difference in mortality between military and a similar cohort of civilian burn injuries. This finding is most likely the result of multiple interventions, most of which have been standardized, to include early closure of the wound coupled with improvements in critical care.

The goal of surgical reconstruction of burn survivors is to restore form and function. Burn and plastic surgeons work among members of the multidisciplinary team to formulate

an operative plan individualized for each patient's priorities. Local tissues are often insufficient and scarred; vascular supply may be compromised; and burned skin simply does not possess the characteristics of normal skin. Not infrequently, flaps consisting of previously burned skin have to be used for reconstruction.

Among 864 active-duty patients admitted to the burn center from 2003 to 2010, 491 patients (57%) underwent acute excision and grafting (Table 1). Among them, 299 (61%) returned to our center for elective reconstructive procedures. This number is likely an underestimation of the true rate of reconstruction because the patients from the latter years are just returning now for their presurgical evaluations. Nevertheless, this retention rate is higher than that seen among civilian burn centers and likely reflects a patient population that is young, active, and provided with easy access to an aggressive rehabilitation program.

As predicted from the injury pattern, the head and neck and the upper extremities bear the brunt of the reconstructive burden: 70% of reconstructive operations are localized to the face and upper extremities compared with 30% on the trunk and lower extremities (Fig. 2). Full-thickness burn to the face and neck results in stigmata, which can include some or all of the following: lower eyelid ectropion, short nose with ala flaring, short retruded upper lip, lower lip eversion, loss of jaw line definition, and lack of neck extension. In the upper extremities, axillary, elbow, wrist, and web space contractures are common. During the past decade, our center has seen increasing use of the pulse-dye laser, either alone or in combination with surgical releases, to improve scar appearance and pliability.[36] Among a subpopulation of severely burned patients, reconstructive procedures continue to this day, more than 8 years after their date of injury and likely for many more years. Common techniques include scar releases in the form of local tissue rearrangements (Z-plasties), skin grafts, pedicle flaps, and microvascular free flaps.[37]

Many patients commence the reconstructive phase of their comprehensive burn care several months to a year after burn to allow for scar maturation as well as reassimilation to life outside of the burn center. There are, however, clear circumstances that dictate earlier surgical interventions such as correction of ectropion to prevent exposure keratitis, correction of microstomia to improve dental hygiene and nutrition, and coverage of exposed bone, tendons, or nerves often seen on bony prominences on the hands, wrists, and elbows to preserve limb. While these procedures are performed before discharge from the hospital, the burden of the disease extends for several years after injury. Research in the use of adipose-derived stem cells harvested from discarded specimens or liposuction fat, injected under early or late burn scars, are currently being investigated.[38] The goal of our research effort is to improve the outcome afforded by current therapies in the form of better results, as well as fewer and less invasive procedures.

BURN REHABILITATION SERVICE

The burn rehabilitation service consists of physical therapists, occupational therapists, physical therapy assistants, and certified occupational therapy assistants; a small number of therapists are also certified as hand therapists. A physician who is board certified in Physical Medicine and Rehabilitation serves as the medical director for the service and as chief of the burn outpatient clinic. The burn rehabilitation service provides comprehensive therapy for all patients admitted to the Burn Center 7 days a week; all patients are assessed, and a plan of therapy is developed within 24 hours of admissions.

War casualties present unique challenges to the rehabilitation team, including managing the combination of burns and other complex injuries.[39] One of second-order effects of improved combat casualty care is survivors with greater disabilities, exemplified by those warriors who return from war with amputations involving one, two, three, or even four extremities. The combination of mangled extremities and burns results in an extreme challenge for the surgeon, rehabilitation therapist, and prosthetist alike. Initial coverage of the exposed bone is complicated by the lack of healthy skin. Excision of the burn skin overlying and amputated limb results in less than optimal coverage for the healing wound. The lack of pliable skin, often replaced by split-thickness skin graft, results in an enormous challenge for the prosthetist as he strives to create the ideal prosthesis.

Hand burns are among the most devastating injuries related to effects of scarring.[40,41] Analysis of combat burn casualties early in the war identified hand burns among those injuries with great potential for prevention and mitigation. Burn therapists are renowned for developing innovative and effective methods of assisting patients in overcoming devastating injuries and lifelong disability; fabrication of customized splints, face masks, and assist devices are key components to therapy.[42]

CONSULTANT SERVICES

Registered dieticians play a crucial role in ensuring early and sustained nutritional support for burn casualties at all phases of their recovery. Improvements in enteral nutrition include tailoring formulations to best meet the needs of our patients and a focused research program to improve our ability to measure nutritional requirements and consistently meet dietary goals. Licensed clinical social workers are instrumental in providing comprehensive support for patients and their families through an often lengthy hospitalization followed by adaptation to lifelong disability.

In the addition to assigned faculty, the Burn Center is fortunate to benefit from the many consultant services required of a Level 1 trauma center. Training programs in orthopedic surgery and ophthalmology provide both immediate consultative services and clinical research collaboration. These relationships have proven essential when caring for war casualties with complex polytrauma including one or more amputations, open fractures, soft tissue injury, eye injuries, and burns.

MILITARY DEPLOYMENT

Although the primary clinical and research responsibilities of USAISR providers reside at our burn center, service in the deployed environment remains both a responsibility and an honor for all uniformed health care providers; the value of

maintaining currency in the practice of deployed combat casualty care cannot be overstated. Much of the insight gained and many of the advances propagated by the Institute since 2001 would not have been feasible without a clinical and research presence on the ground in Iraq and Afghanistan.

Between August 2004 and September 2011, a total of 15 physicians were deployed to Iraq from the USAISR. Generally assigned to the combat support hospital at Ibn Sina Hospital in Baghdad, the physicians served at the epicenter for trauma and burn care within Iraq until it was returned to Iraqi management in 2009. By April 2010, deployment of USAISR physicians shifted from Iraq to Afghanistan, where USAISR personnel are currently serving in both clinical and research capacities.

EDUCATION AND TRAINING

Maintaining a cadre of military medical providers equipped with the knowledge necessary to care for critically injured burn casualties requires a comprehensive education program for all levels of providers. Being able to contribute to graduate medical education programs in the campus is among the tangible benefits of the military's burn center serving the South Texas region as a referral center. Since 2001, more than 400 residents in general surgery, orthopedic surgery, and emergency medicine from across the country have completed month-long rotation in our burn service; more than 50 fellows in surgical, anesthesia, pulmonary, and medical critical care served one or more months in the BICU.

In 2003, the USAISR Burn Center formalized its clinical fellowship in burn surgery, establishing a year-long curriculum to train military and civilian postgraduate surgeons in the art and science of burn care; the fellowship is an additional evidence of its commitment to ensuring a stable cadre of physician leaders in burn care for the Department of Defense as well as the civilian community. Since 2003, 12 surgeons from the Army, Navy, Air Force, and civilian institutions have completed the fellowship.

To ensure optimization of our clinical practice, we rely on a robust performance improvement program to maintain our standards and meet National Patient Safety Goals. Detailed analysis of all patient morbidity and mortality, including postmortem examination, remains an integral component of our performance improvement process and is greatly facilitated by the expertise of a full-time pathologist.[43,44]

Burn Prevention

Burn prevention, generally through education and community outreach, is a key function of a verified burn center. As the sole burn center for the military health care system, our scope of purpose regarding burn prevention applies to all aspects of military life. Our collaborative efforts with other US agencies expanded to include Program Executive Office Soldier and the laboratories at Natick, Maryland, which led the effort to develop and field a new generation of fire-resistant uniforms for our soldiers. Efforts such as the development and fielding of the army combat shirt have contributed to decline in the number and severity of burn injuries.

Modernization

Since BAMC opened its new facility in 1996, it included a modern burn center that included 16 ICU beds and a 24-bed subacute ward, one dedicated OR, and a small rehabilitation gym. It was anticipated that this unit would meet mission requirements for many years to come. Ongoing US military operations following 9/11, combined with population growth in Texas, proved the 1996 facility to be too small. Following a major expansion project, the phased transition of the Burn Center, along with San Antonio Military Medical Center's Level 1 trauma center, into a seven-story tower was completed in May 2012 (Fig. 3).

The military's Burn Center now occupies more than 140,000 sq ft of contiguous space on the fourth floor of San Antonio Military Medical Center. The patient-centered design, using input from both patients and staff members, includes complete modernization of the 16-bed BICU, marked expansion of the burn rehabilitation unit, incorporation of a dedicated outpatient clinic, and the addition of a second OR suite.

Each BICU room is adjoined to a large anteroom that serves as a control point to facilitate infection control practices before the patient care area is entered. Installed within the anteroom are multiple monitors connected to both the patient monitoring system, servers for the electronic health record, and systems supporting clinical research and decision support systems. Advanced electronic support such as this led to BAMC being named a "Most Wired Facility" in 2012.[45]

CLINICAL RESEARCH

The Clinical Trials Task Area is centrally located within the Burn Center; its clinical laboratory is located within the BICU. The mission of the Clinical Trials Task Area is to implement prospective research focused on optimizing combat casualty care for those who have sustained burns and other traumatic injuries. Current studies focused on wound healing include assessments of ReCell and StrataGraf, both in collaboration with the Armed Forces Institute of Regenerative Medicine.

The Combat Casualty Care Engineering Task Area maintains a constant presence within the Burn Center (Fig. 4). Its research team is actively involved in all aspects of BRDSS, electronic wound mapping, and data collection and integration

Figure 3. Acute care in the BICU.

Figure 4. USAISR Burn Center at San Antonio Military Medical Center.

to augment clinical decision making.[14,15] As the science of nursing continues to expand, so has the emphasis placed on capturing knowledge gained in both the deployed and the stateside environments. The Combat Casualty Care Nursing Research Task Area was established to capture the lessons learned and expand the capabilities of nurses at all levels of care, from combat, during *en route* care, and on to in-patient status at the definitive care facility.

All personnel permanently assigned to the Burn Center are afforded opportunities for clinical research. Clinicians work closely with the USAISR's scientists to design and implement translational research related to combat casualty care. During the past 10 years, clinical staff contributed to more than 200 peer-reviewed publications, of which more than 75 discussed burn care. Knowledge gained throughout the war has been shared through presentations at all levels, nationally and abroad. Presentations by Burn Center staff at scientific assemblies have helped disseminate lessons learned for those who will support future military operations as well provide ongoing care at trauma and burn centers worldwide.

FUTURE DIRECTIONS

Lessons learned from our Burn Center's support of combat operations in Iraq and Afghanistan mandate that US military medical support plans include robust capabilities for the treatment of casualties with severe burns, inhalation injury, and complex traumatic injuries. Continuous performance improvement is necessary to ensure that we implement best practices and stewardship of valuable resources. Ongoing research projects remain focused on improving methods of wound healing, reducing scarring and contracture, leveraging technology to optimize resuscitation, and ultimately improving both survival and long-term outcomes of all burn survivors.

AUTHORSHIP

E.M.R., K.K.C., C.E.W., R.K.C., and S.E.W. performed the literature search. E.M.R., B.T.K., and L.R.S. contributed in the study design. E.M.R., B.T.K., K.F.L., and R.K.C. performed the data collection. E.M.R., R.K.C., L.R.S., D.G.B., and L.C.C. performed the data analysis. E.M.R., K.K.C., and J.B.L. performed the data interpretation. E.M.R., B.T.K., K.K.C., J.B.L., C.F.M., L.R.S., A.W.Y., R.K.C., D.G.B., and L.C.C. wrote the article. J.B.L., L.C.C., and L.H.B. provided critical revisions.

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REFERENCES

1. Cancio LC, Horvath EE, Barillo DJ, et al. Burn support for Operation Iraqi Freedom and related operations, 2003 2004. *J Burn Care Rehabil*. 2005;26:151 161.
2. Kauvar DS, Wolf SE, Wade CE, Cancio LC, Renz EM, Holcomb JB. Burns sustained in combat explosions in Operations Iraqi and Enduring Freedom (OIF/OEF explosion burns). *Burns*. 2006;32:853 857.
3. Wolf SE, Kauvar DS, Wade CE, Cancio LC, Renz EM, Horvath EE, White CE, Park MS, Wanek S, Albrecht MA, et al. Comparison between civilian burns and combat burns from Operation Iraqi Freedom and Operation Enduring Freedom. *Ann Surg*. 2006;243:786 792; discussion 792 795.
4. Markell KW, Renz EM, White CE, Albrecht ME, Blackbourne LH, Park MS, Barillo DA, Chung KK, Kozar RA, Minei JP, et al. Abdominal complications after severe burns. *J Am Coll Surg*. 2009;208:940 947; discussion 947 949.
5. Huzar TF, Oh J, Renz EM, Wolf SE, King BT, Chung KK, White CE, Malin E, Lundy JB, Kim SH, et al. *Pneumatosis intestinalis* in patients with severe thermal injury. *J Burn Care Res*. 2011;32:e37 e44.
6. Hardin M, Mace JE, Ritchie JD, Chung KK, Markell KW, Renz EM, Wolf SE, Blackbourne LH, White CE. An experience in the management of the open abdomen in severely injured burn patients. *J Burn Care Res*. 2012; 33:491 496.
7. Lairet KF, Lairet JR, King BT, Renz EM, Blackbourne LH. Prehospital burn management in a combat zone. *Prehosp Emerg Care*. 2012;16: 273 276.
8. Ennis JL, Chung KK, Renz EM, Barillo DJ, Albrecht MC, Jones JA, Blackbourne LH, Cancio LC, Eastridge BJ, Flaherty SF, et al. Joint Theater Trauma System implementation of burn resuscitation guidelines improves outcomes in severely burned military casualties. *J Trauma*. 2008; 64(suppl 2):S146 S151; discussion 151 152.
9. Chung KK, Blackbourne LH, Wolf SE, White CE, Renz EM, Cancio LC, Holcomb JB, Barillo DJ. Evolution of burn resuscitation in operation Iraqi freedom. *J Burn Care Res*. 2006;27:606 611.
10. Chung KK, Wolf SE, Cancio LC, Alvarado R, Jones JA, McCorcle J, King BT, Barillo DJ, Renz EM, Blackbourne LH. Resuscitation of severely burned military casualties: fluid begets more fluid. *J Trauma*. 2009; 67:231 237; discussion 237.
11. Alvarado R, Chung KK, Cancio LC, Wolf SE. Burn resuscitation. *Burns*. 2009;35:4 14.
12. Chung KK, Salinas J, Renz EM, Alvarado RA, King BT, Barillo DJ, Cancio LC, Wolf SE, Blackbourne LH. Simple derivation of the initial fluid rate for resuscitation of severely burned adult combat casualties: in silico validation of the rule of 10. *J Trauma*. 2010;69:S49 S54.
13. Chung KK, Salinas J, Renz EM. Advances in pre-hospital burn resuscitation for the combat injured. *US Army Med Dep J*. 2011:55 60.
14. Salinas J, Chung KK, Mann EA, Cancio LC, Kramer GC, Serio-Melvin ML, Renz EM, Wade CE, Wolf SE. Computerized decision support system improves fluid resuscitation following severe burns: an original study. *Crit Care Med*. 2011;39:2031 2038.
15. Salinas J, Cancio LC, Renz EM, Chung KK, Mann-Salinas EA, Wade CE, Serio-Melvin M, Wolf SE. Computer-assisted decision making in burns fluid resuscitation. *Crit Care Med*. 2012;40:1396 1397.
16. Chung KK, Juncos LA, Wolf SE, Mann EE, Renz EM, White CE, Barillo DJ, Clark RA, Jones JA, Edgecombe HP, et al. Continuous renal

replacement therapy improves survival in severely burned military casualties with acute kidney injury. *J Trauma*. 2008;64(suppl 2):S179 S185; discussion S185 S187.
17. Chung KK, Lundy JB, Matson JR, Renz EM, White CE, King BT, Barillo DJ, Jones JA, Cancio LC, Blackbourne LH, et al. Continuous venovenous hemofiltration in severely burned patients with acute kidney injury: a cohort study. *Crit Care*. 2009;13:R62.
18. Chung KK, Stewart IJ, Gisler C, Simmons JW, Aden JK, Tilley MA, Cotant CL, White CE, Wolf SE, Renz EM. The Acute Kidney Injury Network Criteria Applied in Burns. *J Burn Care Res*. 2012;33:483 490.
19. Stewart IJ, Tilley MA, Cotant CL, Aden JK, Gisler C, Aden JK, Gisler, C, McCorcle J, Renz EM, Chung KK. Association of AKI with adverse outcomes in burned military casualties. *Clin J Am Soc Nephrol*. 2012; 7:199 206.
20. Landoni G, Biondo-Zoccai GG, Tumlin JA, Bove T, De Luca M, Calabro MG, Ranucci M, Zangrillo A. Beneficial impact of fenoldopam in critically ill patients with or at the risk of acute renal failure: a meta analysis of randomized controlled trials. *Am J Kidney Dis*. 2007;49:56 68.
21. Simmons JW, Chung KK, Renz EM, White CE, Cotant CL, Tilley MA, Hardin MO, Jones JA, Blackbourne LH, Wolf SE. Fenoldopam use in a burn intensive care unit: a retrospective study. *BMC Anesthesiol*. 2010; 10:9.
22. Cancio LC. Airway management and smoke inhalation injury in the burn patient. *Clin Plast Surg*. 2009;36:555 567.
23. Edens JW, Chung KK, Pamplin JC, Allan PF, Jones JA, King BT, Cancio LC, Renz EM, Wolf SE, Wade CE, et al. Predictors of early acute lung injury at a combat support hospital: a prospective observational study. *J Trauma*. 2010;69:S81 S86.
24. Chung KK, Renz EM, Cancio LC, Wolf SE. Regarding critical care of the burn patient: the first 48 hours. *Crit Care Med*. 2010;38:1225.
25. Barillo DJ, Renz EM, Wright GR, Broger KP, Chung KK, Thompson CK, Cancio LC. High-frequency percussive ventilation for intercontinental aeromedical evacuation. *Am J Disaster Med*. 2011;6:369 378.
26. Chung KK, Wolf SE, Renz EM, Allan PF, Merrill GA, Shelhamer MC, King BT, White CE, Bekll DG, Schwacha MG, et al. High-frequency percussive ventilation and low tidal volume ventilation in burns: a randomized controlled trial. *Crit Care Med*. 2010;38:1970 1977.
27. Hale DF, Cannon JW, Batchinsky AI, Cancio LC, Aden JK, White CE, Renz EM, Blackbourne LH, Chung KK. Prone positioning improves oxygenation in adult burn patients with severe ARDS. *J Trauma*. 2012; 72:1634 1639.
28. Renz EM, Cancio LC, Barillo DJ, White CE, Albrecht MC, Thompson CK, Ennis JL, Wanek SM, King JA, Chung KK, et al. Long range transport of war-related burn casualties. *J Trauma*. 2008;64(suppl 2): S136 S144; discussion S144 S145.
29. Barillo DJ, Cancio LC, Stack RS, Carr SR, Broger KP, Crew DM, Renz EM, Blackbourne LH. Deployment and operation of a transportable burn intensive care unit in response to a burn multiple casualty incident. *Am J Disaster Med*. 2010;5:5 13.
30. White CE, Renz EM. Advances in surgical care: management of severe burn injury. *Crit Care Med*. 2008;36(suppl 7):S318 S324.
31. Fang R, Dorlac WC, Flaherty SF, Tuman C, Cain SM, Popey TL, Villard DR, Aydelotte JD, Dunne JR, Anderson AM, et al. Feasibility of negative pressure wound therapy during intercontinental aeromedical evacuation of combat casualties. *J Trauma*. 2010;69(suppl 1):S140 S145.
32. D'Avignon LC, Chung KK, Saffle JR, Renz EM, Cancio LC, Prevention of Combat-Related Infections Guidelines Panel. Prevention of infections associated with combat-related burn injuries. *J Trauma*. 2011; 71:S282 S288.
33. Maani CV, Hansen JJ, Fortner PA, Cancio LC, DeSocio PA. Perioperative anesthesia considerations for the burn patient. *Periop Nurs Clin*. 2012; 7:23 34.
34. Maani CV, Desocio PA, Jansen RK, Merrell JD, McGhee LL, Young A, Williams JF, Tyrell K, Jackson BA, Serio-Melvin ML, et al. Use of ultrarapid opioid detoxification in the treatment of US military burn casualties. *J Trauma*. 2011;71:S114 S119.
35. Cancio LC. Surgical care of thermally injured patients on the battlefield. *Periop Nurs Clin*. 2012;7:53 69.
36. Parrett BM, Donelan MB. Pulse dye laser in burn scars: current concepts and future directions. *Burns*. 2010;36:443 449.
37. Mellus D, Chan RK. Reconstructive surgery in the thermally injured patient. *Periop Nurs Clin North Am*. 2012;7:107 113.
38. Chan RK, Zamora DO, Wrice NL, Baer DG, Renz EM, Christy RJ, Natesan S. Development of a vascularized skin construct using adipose derived stem cells from debrided burned skin. *Stem Cells Int*. 2012, Article ID 841203.
39. Hedman TL, Quick CD, Richard RL, et al. Rehabilitation of burn casualties. In: Pasquina PF, Copper PA, eds. *Care of the Combat Amputee*. Washington, DC: Borden Institute; 2010:277 380.
40. Hedman TL, Renz EM, Richard RL, Quick CD, Dewey WS, Barillo DJ, Cancio LC, Baer DG, Wolf SE, Holcomb JB. Incidence and severity of combat hand burns after all army activity message. *J Trauma*. 2008; 64(suppl 2):S169 S172; discussion S172 S173.
41. Chapman TT, Richard RL, Hedman TL, Renz EM, Wolf SE, Holcomb JB. Combat casualty hand burns: evaluating impairment and disability during recovery. *J Hand Ther*. 2008;21:150 158.
42. Dewey WS, Richard RL, Hedman TL, Chapman TT, Quick CD, Renz EM, Blackbourne LH, Wolf SE, Holcomb JB. Opposition splint for partial thumb amputation: a case study measuring disability before and after splint use. *J Hand Ther*. 2009;22:79 86. quiz 87. Epub 2008 Nov 4.
43. Gomez R, Murray CK, Hospenthal DR, Cancio LC, Renz EM, Holcomb JB, Wade CE, Wolf SE. Causes of mortality by autopsy findings of combat casualties and civilian patients admitted to a burn unit. *J Am Coll Surg*. 2009;208:348 354.
44. D'Avignon LC, Hogan BK, Murray CK, Loo FL, Hospenthal DR, Cancio LC, Kim SH, Renz EM, Barillo DJ, Holcomb JB, et al. Contributions of bacterial and viral infections to attributable mortality in patients with severe burns: an autopsy series. *Burns*. 2010;36:773 779.
45. Available at: www.hhnmostwired.com/hhnmostwired/html/previouswinners.html. Accessed July 27, 2012.
46. Chapman TT, Richard RL, Hedman TL, Chisholm GB, Quick CD, Baer DG, Dewey WS, Jones JS, Renz EM, Barillo DJ, et al. Military return to duty and civilian return to work factors following burns with focus on the hand and literature review. *J Burn Care Res*. 2008;29:756 762.